Ecosystem services, an opportunity to improve restoration practices in river corridors ?

Simon Dufour, Anne-Julia Rollet, Johan Oszwald, Xavier Arnauld de Sartre

Ecosystem services, an opportunity to improve restoration practices in river corridors ?

Simon Dufour, COSTEL CNRS UMR LETG - Université Rennes 2, simon.dufour@univ-rennes2.fr
Anne-Julia Rollet, GEOPHEN CNRS UMR LETG - Université Caen Basse Normandie, anne-julia.rollet@unicaen.fr
Johan Oszwald, COSTEL CNRS UMR LETG - Université Rennes 2, johan.oszwald@univ-rennes2.fr
Xavier Arnauld de Sartre, CNRS UMR SET, xavier.arnauld@univ-pau.fr

Key words: ecosystem services, riparian vegetation, river restoration, ecosystem functions, reference conditions, rehabilitation, human well-being

Abstract: The ecological and socio-economic functions of river and riparian ecosystems are broadly recognised. In this article, we aim to highlight the opportunity that ecosystem services can represent in the improvement of management practices in river and floodplain systems, specifically with regards to the definition of the objectives in restoration projects. We discuss how the concept of ecosystem services can be used (i) to move from reference-based to objective-based projects, (ii) to promote a real integrated approach merging scales and disciplines, (iii) to provide comprehensible and concrete arguments for project implementation and (iv) to include human-made features and ecosystems and to promote a well-balanced relationship between Man and Nature.

Introduction

The ecological and socio-economic values of river and floodplain ecosystems are now broadly recognised (Naiman *et al.*, 2005). Recently, the concept of ecosystem services has given a new formalisation to this recognition (Lovett *et al.*, 2004; Postel, 2008). Ecosystem functions are beneficial to human populations, directly or indirectly, through ecosystem goods and services (Costanza *et al.*, 1997; Daily, 1997; Millennium Ecosystem Assessment, 2005; Patterson and Coelho, 2009). They are variable in nature and scale but they all participate in human well-being (i.e. good social relations, security, freedom, necessary material for a good quality of life; see Millennium Ecosystem Assessment, 2005) and some of them could not be replaced by technology. Fundamentally ecosystem services approach need a multidisciplinary framework based on ecological, economical, sociological and historical assessments.

The idea that ecosystems provide a large range of functions and services that can be valued is not new (Gosselink *et al.*, 1974) but a real development of this concept was observed during the 1990s (Costanza *et al.*, 1989; Point, 1992; Daily, 1997; Costanza, 2000 ; Daily *et al.*, 2000). This idea is partially based on the work done since the 1960s by economists that have developed methods for estimating the benefits of natural environments and it was used by some ecologists in the 1970s and 1980s. The recent impulse, notably due to the Millennium Ecosystem Assessment process, gives us the opportunity to debate about the help that this notion can provide for improving our way to restore fluvial corridors. The objective of this short article is not to discuss the definition, list and classification of services provided (i.e. benefits, services, goods... see Daily, 1997; Millennium Ecosystem Assessment, 2005; Boyd and Banzhaf, 2006; Wallace, 2007; Fischer and Turner, 2008) nor the methods to economically evaluate such systems, but rather to highlight the opportunity that this concept can represent (or not) in order to enhance some aspects usually neglected in the definition of the objectives in restoration projects dealing with river and riparian systems (Dufour and Piégay, 2009) and to propose restoration topics from a new angle.

Issues in fluvial corridor restoration

After hundreds years of modification in fluvial corridors, the last two decades have been characterised by a significant increase in restoration projects and alternative management practices (Boon *et al.*, 1992; Ormerod, 2004). Firstly, they were based on the recognition that human actions, notably since the industrial revolution, have deeply degraded (natural) environments and that the integrity of river and riparian systems has been affected by the decrease in the expression of dynamic processes that drive natural systems (channel mobility, flooding, sediment transfer). As a result, most of the restoration projects promoted respectively a return to prior disturbance conditions and, then, to more dynamic conditions. Restoration frameworks have evolved over the last two decades, however we still often failed to base projects on clear objectives defined as a combination of what we can have and what we want (Palmer *et al.*, 2005) and to target explicitly both natural system integrity and human well-being (Dufour and Piégay, 2009). Indeed, it cannot be argued that to systematically and uniformly restore processes such as flooding, bed mobility or sediment transport is always favourable to riverine societies and to all ecosystems. It can be counter productive, and thus lead to a failure in project implementation, focusing only on ecological integrity enhancement and forgetting human well-being, even though they do not necessarily compete against one other. Scientists carried out some experiments in order to understand the pattern or functioning of fluvial corridors in a broad variety of geographical environments. However some issues linked to the appreciation of society's needs and wishes deeply limit the effectiveness of these projects. We can therefore ask the following questions: (i) how do we identify society's wishes as it is a complex system of stakeholders? (ii) How do we deal with multiple (and competitive) issues in the same area and within the same watershed? And, (iii) do scientists and environmentalists have rational and audible arguments to present to society and politics concerning ecosystem restoration or preservation? In this context, we assume that the identification of ecosystem services provided by fluvial corridors can partially answer these questions.

Services provided by rivers and riparian areas

River systems and riparian areas provide a wide range of services to human populations (Table 1), notably because they are a key component in many biogeochemical cycles and global biodiversity (Naiman and Décamps, 1997; Tabacchi *et al.*, 2000) and these services are seen to hold an important economical value. Indeed, in the global assessment done by Costanza *et al.* (1997), the economic value of swamps, floodplains, lakes and rivers is very high (i.e. 4931 x 10^9 US$.yr^{-1} or 14.82 % of the total for the 17 ecosystem types integrated in the evaluation) although they represent a relatively small area (0.71 % of the total studied area). And this is most likely a huge underestimation because river systems have a specific shape and size that makes it difficult to evaluate on a large scale (Konarska *et al.*, 2002). Services provided by inland water ecosystems are probably the most affected by historical changes (Millennium Ecosystem Assessment, 2005) notably because they have been providing a wide range of services for a long time and so they have been deeply modified by human activities. Indeed both traditional uses (water, angling, hydraulic power, mills, wood, grazing and navigation) and more modern ones (canoeing, leisure angling and recreation) affect hydrosystems functioning at varying magnitudes depending on the nature, intensity and timing of the impact generated by these uses. For river managers, the complexity is notably linked to the fact that one reach is usually concerned by several issues that can be competitive, such as navigation and channel mobility (Dufour *et al.*, 2008), or complementary, such as aesthetic value and bird habitat of the riparian vegetation (Hale *et al.*, 2005).

Table 1. Examples of services, goods and benefits associated with river and riparian vegetation (see Holmlund and Hammer, 1999; Loomis *et al.*, 2000; Seyam *et al.*, 2001; Boutin *et al.*, 2003; Lovett *et al.*, 2004; Sweeney *et al.*, 2004; Emerton and Bos, 2004; Millennium Ecosystem Assessment, 2005; Brauman *et al.*, 2007; Morand and Dann, 2008; Postel, 2008; Lees and Peres, 2008; Butler *et al.*, 2009; Posthumus *et al.*, 2010)

Services, goods, benefits	***Comments***	***Examples of restoration practices***
Food, fibre, wood, grazing..	Not specific but in several contexts river and riparian ecosystems have a higher productivity than surrounding areas	Limit channel degradation and associated ground water decline to insure high productivity
Delivery of sediment and nutrients to deltas and estuaries	Changes in the watershed and network can deeply modify sedimentary and the food web equilibrium of deltas	Limit discontinuities in the fluvial systems that hamper the transfer downstream, allow bank erosion
Fresh water supply	Supply by pumping directly in the channel or ground water in the floodplain	Enhance channel/groundwater connectivity, limit channel degradation
Water regulation	Both floods and droughts can be mitigated	Favour large flooded area occupied by adapted vegetation and no constructions
Water purification	Changes in water quality can be due to trapping effect, denitrification... by riparian vegetation	Favour strips of spontaneous vegetation along river banks, limit channel degradation
Erosion control	Vegetation can protect bank from erosion ; note, that means that erosion is something to fight against whereas we know that lateral mobility also provides some services (Florsheim *et al.*, 2008) and can be managed by alternative options (Piégay *et al.*, 2005)	Favour native vegetation more than rock riprap protections, or development of alternative options such riverine land acquisition
Recreation and tourism	The association of water and forests is positively appreciated for several activities such as fishing, canoeing, swimming or aesthetic enjoyment	Dedicate some areas to such activities to channel the public into appropriated zones
Educational values	Rivers and riparian areas provide sites for formal and informal education	Create some information points or paths for the public in well equipped zones
Fisheries	Angling can be commercial or otherwise; fish populations benefit in various ways from river and riparian ecosystems: habitat, food, shade...	Planting trees along the bank; restore processes needed for the natural generation of riparian species, enhance aquatic habitat availability
Fauna and flora conservation	Rivers and riparian areas provide a habitat for numerous species and connectivity between sub-populations	Favour large flooded areas occupied by spontaneous vegetation, restore connectivity

Opportunity for using ecosystem services framework

On a regional scale, rivers and floodplains are recognised as highly valued ecosystems providing several services to protect and restore (Raymond *et al.*, 2009). For example, on the Ain River a recent project of sediment reintroduction aims to preserve several endangered services because of the sediment deficit: drinking water and irrigation, fishing, canoe and patrimonial valuable ecosystems (Rollet *et al.*, submitted). So, the opportunity to use ecosystem services to improve restoration practices should be discussed (Tong *et al.*, 2007), and we suggest focusing on 4 points:

1. To move from reference-based to objective-based projects
2. To promote a real integrated approach merging scales and disciplines
3. To provide comprehensible and concrete arguments for project implementation
4. To include human-made features and ecosystems and to promote a well-balanced relationship between Man and Nature

Point 1. The use of ecosystem services is probably one option to avoid restoration projects based solely on the idea of recovering the historical state or functioning and so to move from reference-based to objective-based projects (Dufour and Piégay, 2009). If restoration objectives are defined as the combination of what we can have (i.e. potential functioning) and what we want (i.e. society's wishes), we could consider that processes needed to reach the potential functioning (what we can have) are currently well documented, whereas what we want is more difficult. Ecosystem services could represent a good possibility to address this question (Figure 1). Indeed, in the Millennium Ecosystem Assessment approach, ecosystems' health is not related to any preferred state but to the ability to provide a particular set of services. Thus, this approach focuses on end objectives that sustain human well-being. So the restoration of one or several processes (i.e. services) is a mean and not a goal *per se*. It is assumed that the reflection should be based on current and future conditions and needs which guarantee the relevance of the restoration project on a long term basis (see for example Comin *et al.*, 2010). The definition of such an objective "does not imply that ecosystems are not also valuable for other reasons, but that ecosystem services are defined as the instrumental values of ecosystems as a means to an end of human well-being" (Costanza, 2008). The ecosystem services are defined from the diagnosis of the studied area that mixes historical trajectory and functional site analysis. Indeed, historical land cover dynamics can be essential in explaining the current landscape structure and ecosystem services production (Arnaud de Sartre *et al.*, 2010). Moreover, functional and dynamic sites provide a range of variability benchmarks (Ward *et al.*, 2001).

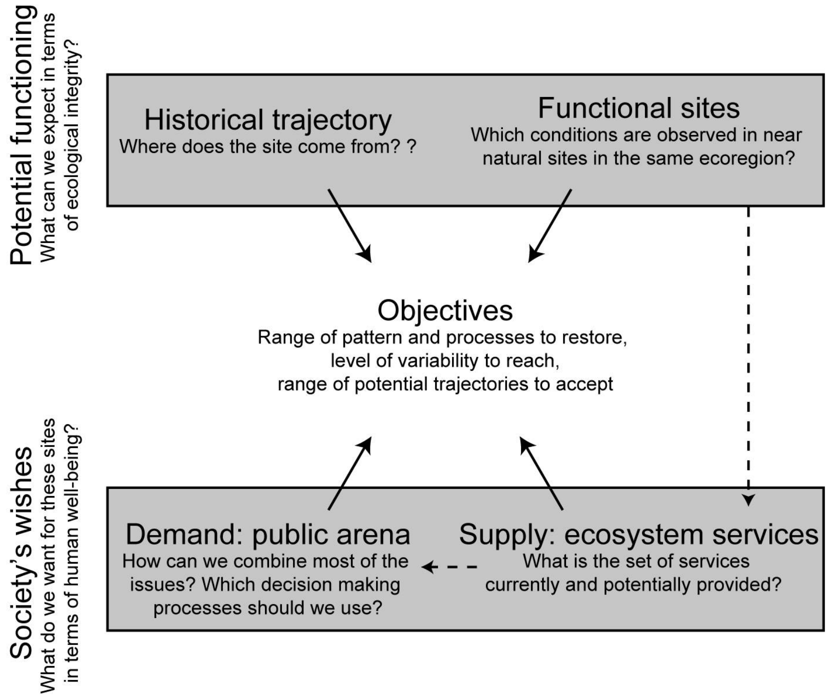

Figure 1: potential role of ecosystem services in the definition of a restoration project's objectives (modified from Dufour and Piégay, 2009).

Point 2. The definition of provided services (potentially) allows the identification of all issues and thus helps the political debate for establishing priorities (priorities not only fo biota but also for society) (Figure 1). Then, a complex scheme that combines sociological, economical and political drivers should guide the choice of objectives. To provide useful information for the debate, real multidisciplinary and multiscale approaches are needed (Figure 2) (See also Termorshuizen and Opdam, 2009; Beechie *et al.*, 2010). This is a very good opportunity to highlight some needs that have been underestimated and understudied over decades and thus an opportunity to take into account all stakeholders. Indeed, rivers and riparian areas are typically located where high biodiversity, conservation values and numerous human issues coexist. However, over the last centuries, and especially after WWII, some of the issues have been

underestimated for several reasons: lack of knowledge of the ecosystems pattern and functioning, decision-making processes that favour some uses due to powerful lobbying of some stakeholders or the focusing on the most obvious and easily valuable issues (Jewitt, 2002; Wang *et al.*, 2009). The inclusion of the beneficiaries of the services "makes values intrinsic to ecosystem services; whether or not those values are monetized, the ecosystem services framework provides a way to assess trade-offs among alternative scenarios of resource use" (Brauman *et al.*, 2007, see also Egoh *et al.*, 2007).
Moreover, because the notion of ecosystem services deals with various dimensions of reality, it should be a spatially explicit framework that integrates local actions on a broader scale (Beechie *et al.*, 2010; Paetzold *et al.*, 2010) and needs to integrate geographical context which is sometimes underestimated in restoration projects with both human and natural specificity (Brierley and Fryirs, 2009). For example, upstream to downstream solidarity takes into account that the local expression of a service can be linked to local conditions but also to catchment characteristics (Walsh *et al.*, 2007). Moreover, the need to research the better level to define and pay for ecosystem services also gives an opportunity to address some crucial scientific questions such as, what would be the most relevant scale to support efficient interactions between ecosystems and services? At what scale are the interactions between the ecological function and processes? The geographic approach, that is fundamentally integrated (i.e. combination of several disciplines) and scale based, is thus well adapted to assess ecosystem conditions, service provisions and human needs on a given area.

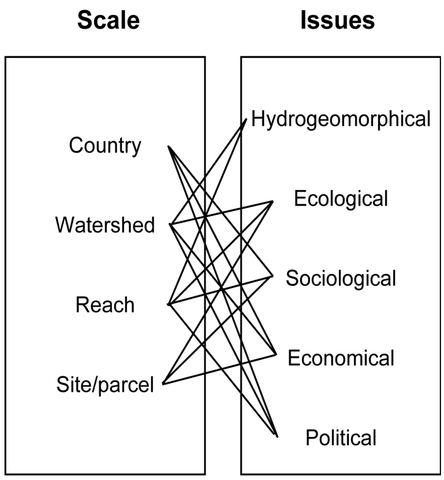

Figure 2: multiple scales and issues to articulate in the identification and characterisation of ecosystem services.

Point 3. Ecosystem services can be important to illustrate the link between natural resources and human well-being (Wallace, 2008) and also to provide comprehensible and concrete arguments for decision making processes. For example, such approaches can provide tools for negotiation between stakeholders as they have to discuss the objectives (which benefit?) before the means (which function?) and to minimise harmful impacts of actions on each service (Chee, 2004; Raymond *et al.*, 2009). For services that can be economically evaluated, tools have been used for several decades and are well identified (Narayanan, 1986; Loomis and Creel, 1992). The interest of economical valuation can be to prove that the costs of protecting, acquiring and restoring are lower than the costs generated by loosing the provided services (see for example Homles *et al.*, 2004 for riparian restoration, Postel and Thompson, 2005 for water supply at watershed scale or Wang *et al.,* 2009 for hydropower development). Thus, the economic evaluation of ecosystem services can be used to justify a change in management practices, to set up a restoration project and to allocate public or private resources to such a project (Loomis, 1996; Loomis *et al.*, 2000; Emerton and Bos, 2004).

Moreover, information "about the use and passive use values of the restoration project can aid decision-makers in selecting restoration projects that provide the greatest benefits to society as a whole" (Loomis, 2006). This argument also supports some projects that are difficult to implement because their cost seems to be expensive in relation to the benefits achieved. The notion of ecosystem services also shows that the projects usually omit an important number of passive use values. For example, along the Snake River, dam removal has been shown as economically efficient by including passive use values (Loomis, 2006). However, the ecosystem services framework can not be limited to the economical evaluation of provided services as this approach focus on the demand (which is limited by stakeholder perception and representation) and not the supply of services. We assume that economical evaluation of services is a tool for education and dialogue but must not be the only criteria for restoration success assessment which has to also consider social and cultural perspectives (see Chee, 2004; Spangenberg and Settele, 2010; Kumar, 2010 for critics and alternative approaches). It is not because economic evaluation is the main way to quantify the value of a service that it is the more pertinent indicator of this service.

Point 4. From a theoretical perspective, the notion of ecosystem services appears as a strictly anthropocentric and utilitarianism approach because human well-being is the central focus. However, the conceptual framework defined by the Millennium Ecosystem Assessment (2005) recognises that biodiversity and ecosystems also have an "intrinsic value and that people take decisions concerning ecosystems based on considerations of both well-being and intrinsic value". The "service" angle does not necessary deny the intrinsic value of ecosystems but just rationalises one face of the man/nature relationship. It is an alternative approach to biocentric and anthropocentric perspectives, more realistic than the first one and broader than the second. This alternative way regarding relationships between Man and Nature is probably more efficient for applied issues and could be related to the ecocentric position (Larrère and Larrère, 2007) or weak anthropocentrism (Norton, 1984). Restoration of ecosystem services is interesting not only for the service itself but also because it participates in building well balanced relationships between man and nature with rights and duties for human populations (see also Gobster and Hull, 2000). Moreover, the notion of ecosystem services allows to overcome the traditional distinction between natural and humanised ecosystems where ecosystems influenced by humans are systematically perceived as degraded. Thus human made features or situations can be included if they support processes that provide services. In this acceptance, natural and cultural objects are not opposed as they are traditionally in western culture (Rappapport, 1984; Descola, 1986; Latour, 1991).

Perspectives and conclusions

If the ecosystem services concept formalised a comprehensive framework, several questions have to be answered (Millennium Ecosystem Assessment, 2005; Egoh *et al.*, 2007; de Groot *et al.*, 2009; Garrick *et al.*, 2009; Termorshuizen and Opdam, 2009; Paetzold *et al.*, 2010) such as:

- understanding, modelling and forecasting relations between ecosystem spatial patterns, functioning and services,
- developing methods for service identification and evaluation that integrate the different scale levels,
- enhancing governance and decision making processes, applying this notion to real projects.

Indeed, regarding river and riparian systems, a better understanding of links between forms, processes and services is needed. How does the spatial pattern of the fluvial corridor influence the hydrological, morphological, chemical and biological functioning? How do different patterns and functionalities drive the services provided locally and at watershed scale? To answer these questions an upscaling is essential (Beechie *et al.*, 2008).

For example, we know that scale riparian vegetation can significantly reduce pollutant fluxes. However, a quantitative upscaling of local effects at the watershed scale is still difficult to appreciate without a clear understanding of geographical variability in riparian vegetation functioning and pattern at this network scale. Here, GIS and remote sensing tools can provide located, high resolution and continuous information (Carbonneau *et al.*, 2004; Alber and Piégay, 2011; Chen, 2009; Wiederkehr *et al.*, 2010; Pert *et al.*, 2010) that integrates the position of the objects in the landscape (Mitsch and Gosselink, 2000), spatial relationships between features and reaches and location of services and beneficiaries (Egoh *et al.*, 2007). The resolution is notably important for streams and small riparian strips due to their size and shape that greatly influence our ability to map services (Troy and Wilson, 2006). The question of coherence between the spatial scale at which services are generated and the institutional scales at which stakeholders benefit from services issues also needs to be addressed (Wilbanks, 2006; Hein *et al.*, 2006).

The identification and scalability of the ecosystem services and their values (especially intrinsic ones) is also a challenge that should mobilise several disciplines ranging from ecology to sociology. It seems essential to merge scientific diagnosis to various "local people" perspectives (Raymond *et al.*, 2009; Paetzold *et al.*, 2010) because very contradictory points of view can be expressed on the same subject (Calder, 2002; Netusil, 2006). So, we obviously need to make some progress in the scientific understanding of services but also to create appropriate conditions and framework in order to have some constructive exchanges between stakeholders and tools to solve contradiction (Mooney, 2010). The role of vegetation on bank stability is an interesting example. From the landowner or farmer's point of view riparian vegetation provides a service when it limits bank erosion (Lovett *et al.*, 2004) but from an environmentalist perspective lateral mobility is a necessary process for the regeneration of pioneer vegetation and thus biological integrity of the system (Florsheim *et al.*, 2008). Once this contradiction is set up, a compromise has to be found by negotiation or changes in management strategy (Piégay *et al.*, 2005). But how?

Ecosystem service is not a totally stabilised notion and several implications are still under debate (philosophical, economical and governance aspects for example). Nor is it a magic way to solve all problems in restoration project implementation (Palmer et Filoso, 2009). For example, it will not solve dialogue, institutional and decision-making problems and it is not designed to integrate potential constraints generated by ecosystems such as modification of flood conditions induced by wood in a river or water consumption by vegetation during the summer in Mediterranean and semi-arid watersheds. If it is not a substitute to other frameworks (e.g. water footprint, adaptive resource management...) it has to be a complementary approach to improve our practices (Norgaard, 2010).

From a scientific perspective, of course some physically and biologically based questions still need to be addressed: thresholds, regime shift, feedback, complex interactions et cetera, but the main challenge is probably to explore more systematically the links between hydrology-geomorphology-ecology on the one hand and sociology-anthropology-economy on the other. How, when and where does a riparian strip or reach provides a (or several) service? The economical evaluation has experimented on an important development over the last decade but, as discussed above, it cannot be the only way to take into account socio-economical issues in restoration projects.

The efficiency of this notion to enhance restoration practices is related to the trajectory that it will follow (and thus how the scientific community will work on it). If it is reduced to an economical tool for natural feature evaluation, the gain would be significant but very delusive (Palmer et Filoso, 2009), and many sociological and cultural aspects of restoration paradigm would be omitted. If it is used to place the relationship between humans and nature at the centre of the projects it would perhaps progress more, especially if humans are taken in the broader sense, that is to say not limited to scientific and environmentalist communities. It is also a chance for ecosystems to reach a better integrity by a better appreciation of their irreplaceability. To reach such a goal, we should not consider services provided against intrinsic values of ecosystems but rather useful with intrinsic values.

Acknowledgments: Funding was provided by the ANR Program AGES

Date: Marsh 2010-January 2011

References

Alber A, Piégay H. 2011. Spatial disaggregation and aggregation procedures for characterizing fluvial features at the network-scale: Application to the Rhône basin (France). Geomorphology 125: 343-360

Arnauld de Sartre X, Castro M, Hubert B, Oszwald J, Lavelle P. 2010. Scalar organization of reality and social diversity in the ecosystem services assessment. In: Annual Meetings of the Association of American Geographers, Washington, D.C., April 14-18, 2010.

Beechie TJ, Pess GR, Roni P. 2008. Setting river restoration priorities: a review of approaches and a general protocol for identifying and prioritizing actions. North American Journal of Fisheries Management 28: 891–905.

Beechie TJ, Sear DA, Olden JD, Pess GR, Buffington JM, Moir H, Roni P., Pollock MM. 2010. Process-based Principles for Restoring River Ecosystems. BioScience 60: 209-222.

Boon PJ, Calow P, Petts GE (eds). 1992. River conservation and management. John Wiley & Sons, Chichester, 470 p.

Boutin C, Jobin B, Bélanger L. 2003. Importance of riparian habitats to flora conservation in farming landscapes of southern Québec, Canada. Agriculture, Ecosystems and Environment 94: 73–87

Boyd J, Banzhaf S. 2006.What are ecosystem services? the need for standardized environmental accounting units. Ecological Economics 63: 616–626.

Brauman KA, Daily GC, Duarte TK, Mooney HA. 2007.The nature and value of ecosystem services: an overview highlighting hydrologic services. Annual Review of Environment and Resources 32: 67–98.

Brierley G, Fryirs K. 2009. Don't fight the site: three geomorphic considerations in catchment-scale river rehabilitation planning. Environmental Management 43 : 1201–1218.

Butler JRA, Radford A, Riddington G, Laughtona R. 2009. Evaluating an ecosystem service provided by Atlantic salmon, sea trout and other fish species in the River Spey, Scotland: The economic impact of recreational rod fisheries. Fisheries Research 96: 259–266

Calder IR. 2002. Forests and hydrological services: reconciling public and science perceptions. Land Use and Water Resources Research 2: 2.1–2.12

Carbonneau PE, Lane SN, Bergeron NE. 2004. Catchment-scale mapping of surface grain size in gravel-bed rivers using airborne digital imagery. Water Resources Research 40(7): W07202. DOI:10.1029/2003WR002759.

Chee YE. 2004. An ecological perspective on the valuation of ecosystem services. Biological Conservation 120: 549–565

Chen N, Li H, Wang L. 2009. A GIS-based approach for mapping direct use value of ecosystem services at a county scale: Management implications. Ecological Economics 68: 2768-2776.

Comín FA, Sorand R, Mirand B, Guara L, Moliner S, Calvo A. 2010. River and watershed restoration through the assessment of ecosystem services. In : 7th European Conference on Ecological Restoration, August 2010, Avignon, France.

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruedo J, Raskin RG, Sutton P, van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253-260

Costanza R, Farber SC, Maxwell J. 1989. Valuation and management of wetland ecosystems. Ecological Economics 1: 335-361

Costanza R. 2008. Ecosystem services: multiple classification systems are needed. Biological Conservation 141: 350–352

Costanza R, 2000. Societal goals and the valuation of ecosystem services. Ecosystems 3: 4–10.

Costanza R, D'Arge R, de Groot RS, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, van den Belt M. 1997. The value of the world's ecosystem services and natural capital. Nature 387: 253–260.

Daily GC (ed). 1997. Nature's services: societal dependence on natural systems. Island Press, Washington, DC, 392 p.

Daily GC, Söderqvist T, Aniyar S, Arrow K, Dasgupta P, Ehrlich PR, Folke C, Jansson AM, Jansson BO, Kautsky N, Levin S, Lubchenco J, Mäler KG, Simpson D, Starrett D, Tilman D, Walker B. 2000. The value of nature and the nature of value. Science 289: 395–396.

de Groot RS, Alkemade R, Braat L, Hein L, Willemen L. 2009. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity in press

Descola P. 1986 ; 1986, La Nature domestique : symbolisme et praxis dans l'écologie des Achuar, Paris, Fondation Singer-Polignac et Éditions de la Maison des Sciences de l'Homme, 450 p. (see, for an english version, Cambridge University Press, 1994).

Dufour S, Provansal M, Raccasi G. 2008. Can flood risk management restore ecogeomorphologic functioning of fluvial margins along the Rhône River (France, SE)? 4th ECRR International Conference on River Restoration, 16-21th june 2008, Venice, Italia.

Dufour S, Piégay H. 2009. From the myth of a lost paradise to targeted river restoration: forget natural references and focus on human benefits. River Research and Applications 25: 568-581.

Egoh B, RougetM, Reyers B, KnightAT, Cowling RM, van Jaarsveld AS, Welz A. 2007. Integrating ecosystem services into conservation assessments: A review. Ecological Economics 63: 714-721.

Emerton L, Bos E. 2004. Value. Counting ecosystems as aneconomic part of water infrastructure. IUCN, Gland, Switzerland and Cambridge, UK. 88 pp.

Fisher B, Turner RK. 2008. Ecosystem services: Classification for valuation. Biological Conservation 141 : 1167–1169.

Florsheim JL, Mount JF, Chin A. 2008. Bank erosion as a desirable attribute of rivers. BioScience 58: 519-529

Garrick D, Siebentritt MA, Aylward B, Bauer CJ, Purkey A. 2009. Water markets and freshwater ecosystem services: Policy reform and implementation in the Columbia and Murray-Darling Basins. Ecological Economics 69: 366–379

Gobster P, Hull R (eds). 2000. Restoring Nature. Perspectives from the social sciences and humanities. Island Press, 269 p.

Gosselink JF, Odum EP, Pope RP 1974. The value of the tidal marsh. enter for Wetland Resources, Louisiana State University, Baton Rouge, LA. Publ. No. LSU-SC-74-04, unpublished report

Hale BW, Steen-adams MM, Predik K, Fisher N. 2005.Ecological conservation through aesthetic landscape planning: a case study of the Lower Wisconsin State Riverway. Environmental Management 35: 381–395.

Hein L, van Koppen K, de Groot RS, van Ierland EC. 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57: 209– 228

Holmes TP, Bergstrom JC, Huszar E, Kask SB, Orr F. 2004. Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. Ecological Economics 49: 19– 30.

Holmlund CM, Hammer M. 1999. Ecosystem services generated by fish populations. Ecological Economics 29: 253–26.

Jewitt G. 2002. Can integrated water resources management sustain the provision of ecosystem goods and services? Physics and Chemistry of the Earth 27: 887–895.

Konarska KM, Sutton PC, Castellon M. 2002. Evaluating scale dependence of ecosystem service valuation: a comparison of NOAA-AVHRR and Landsat TM datasets. Ecological Economics 41: 491–507.

Kumar M, Kumar P. 2010. Valuation of the ecosystem services:apsycho-cultural perspective. Ecological Economics 64: 808 – 819

Larrère R, Larrère C. 2007. Souhld nature be respected ? Social Science Information 46: 9-34.

Latour B. 1991. Nous n'avons jamais été modernes - essai d'anthropologie symétrique. Edition La Découverte, Paris, 207 p (see, for an english traduction, We have never been modern, Harvard University Press, 1993).

Lees AC, Perez CA. 2008. Conservation value of remnant riparian forest corridors of varying quality for amazonian birds and mammals. Conservation Biology 22: 439–449

Loomis J, Kent P, Strange L, Fausch K, Covich A. 2000 ; Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics 33: 103–117

Loomis J. 1996. Measuring the economic benefits of removing dams and restoring the Elwha River: results of a contingent valuation survey. Water Resources Research 32: 441-447.

Loomis J. 2006. Importance of including use and passive use values of river and lake restoration. Journal of Contemporary Water Research & Education 134: 4-8.

Loomis JB, Creel M. 1992. Recreation benefits of increased flows in California’s San Joaquin and Stanislaus Rivers. Rivers 3: 1-13.

Lovett S, Price P, Cork S. 2004. Riparian ecosystem services. Fact Sheet 12, Land & Water Australia, Canberra, unpublished report, available at www.fetwater.co.za (06/06/2010).

Millennium Ecosystem Assessment 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, DC, available at www.millenniumassessment.org (06/06/2010).

Mitsch WJ, Gosselink JG. 2000. The value of wetlands: importance of scale and landscape setting. Ecological Economics 35: 25–33.

Mooney HA. 2010. The ecosystem-service chain and the biological diversity crisis. Philosophical Transaction of the Royal Society B 365: 31–39

Morand D, Dann S. 2008. The economic value of water use: Implications for implementing the Water Framework Directive in Scotland. Journal of Environmental Management 87, 484–496.

Naiman RJ, Décamps H. 1997. The ecology of interfaces : riparian zones. Annual Review of Ecology and Systematics 28: 621-658.

Naiman RJ, Decamps H, McClain M. 2005. Riparia, ecology, conservation, and management of

streamside communities. Academic Press, Elsevier, San Diego 430 p.
Narayanan R. 1986. Evaluation of recreational benefits in instream flows. Journal of Leisure Research 18: 116-128.
Netusil NR. 2006. Economic valuation of riparian corridors and upland wildlife habitat in an urban watershed. Journal of Contemporary Water Research & Education 134: 39-45.
Norgaard RB, 2010. Ecosystem services: From eye-opening metaphor to complexity blinder. Ecological Economics 69: 1219–1227.
Norton BG. 1984. Environmental ethics and weak anthropocentrism. Environmental Ethics 6: 131–148.
Ormerod SJ. 2004. A golden age of river restoration science? Aquatic Conservation: Marine and Freshwater Ecosystems 14: 543-549
Paetzold A, Warren PH, Maltby LL. 2010. A framework for assessing ecological quality based on ecosystem services. Ecological Complexity, 7: 273-281
Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm C, Follstad Shah J, Galat DJ, Gloss S, Goodwin P, Hart DH, Hassett B, Jenkinson R, Kondolf GM, Lave R, Meyer JL, O'Donnell TK, Pagano L, Srivastava P, Sudduth E. 2005. Standards for ecologically successful river restoration. Journal of Applied Ecology 42: 208–217.
Palmer MA, Filoso S. 2009. Restoration of ecosystem services for environmental markets. Science 325: 575-576.
Patterson TM, Coelho DL. 2009. Ecosystem services: Foundations, opportunities, and challenges for the forest products sector. Forest Ecology and Management 257: 1637–1646
Pert PL, Butler JRA, Brodie JE, Bruce C, Honzák M, Kroon FJ, Metcalfe D, Mitchell D, Wong G. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. Ecological Complexity 7: 378-388.
Piégay H, Darby SE, Mosselman E, Surian N. 2005. A review of technique available for delimiting the erodible river corridor: a sustainable approach for managing bank erosion. River Research and Applications 21: 773-789.
Point P. 1992. Les services rendus par le patrimoine naturel : une évaluation fondée sur des principes économiques. Economie et statistique 258: 11-18.
Postel SL, Thompson BH. 2005. Watershed protection: Capturing the benefits of nature's water supply services. Natural Resources Forum 29: 98–108.
Postel SL. 2008. The forgotten infrastructure :safeguarding freshwater ecosystems. Journal of International Affairs 61: 75-90.
Posthumus H, Rouquette JR, Morris J, Gowing DJG, Hess TM. 2010. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69: 1510–1523
Rappaport RA. 1984. Pigs for the ancestors: ritual in the ecology of a New Guinea people. Yale University Press, Second (revised) edition, New Haven, 501 p.
Raymond CM, Bryan BA, MacDonald DH, Cast A, Strathearn S, Grandgirard A, Kalivas T. 2009. Mapping community values for natural capital and ecosystem services. Ecological Economics 68: 1301–1315
Rollet AJ, Piégay H, Lejot J, Bornette G, Dufour S, Persat H. submitted. Integrating process-thinking and long term perspective in restoration of dammed reaches : lessons from the sediment reintroduction experiences on the Ain River pilot site, France. River Research and Applications.
Seyam IM, Hoekstra AY, Ngabirano GS, Savenije HHG. 2001. The value of freshwater wetlands in the Zambezi basin. Value of Water Research Report Series No. 7, unpublished report, available at www.wem.ctw.utwente.nl (06/06/2010).
Spangenberg JH, Settele J. 2010. Precisely incorrect? Monetising the value of ecosystem services. Ecological Complexity 7: 327-337
Sweeney BW, Bott TL, Jackson JK, Kaplan LA, Newbold JD, Standley LJ, Hession WC, Horwitz RJ. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. PNAS 101: 14132–14137.
Tabacchi E,Lambs L, Guilloy H, Planty-Tabacchi AM, Muller E, Décamps H. 2000. Impacts of riparian vegetation on hydrological processes. Hydrological Processes 14: 2959-2976.
Termorshuizen JW, Opdam P. 2009. Landscape services as a bridge between landscape ecology and sustainable development. Landscape Ecology 24: 1037–1052.
Tong C, Feagin RA, Lu J, Zhang X, Zhu X, Wang W, He W. 2007 Ecosystem service values and restoration in the urban Sanyang wetland of Wenzhou, China. Ecological Economics 29: 249–258.
Troy A, Wilson MA. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics 60: 435–449.
Wallace K. 2008. Ecosystem services: Multiple classifications or confusion? Biological Conservation 141 : 353–354.
Wallace KJ. 2007. Classification of ecosystem services: problems and solutions. Biological Conservation 139: 235–246.
Walsh CJ, Waller KA, Gehling J, MacNally R. 2007. Riverine invertebrate assemblages are degraded more by catchment urbanisation than by riparian deforestation. Freshwater Biology 52: 574–587
Wang G, Fang Q, Zhang L, Chen W, Chen Z, Hong H. 2009. Valuing the effects of hydropower development on watershed ecosystem services:

Case studies in the Jiulong River Watershed, Fujian Province, China. Estuarine, Coastal and Shelf Science 86, 363-368.
Ward JV, Tockner K, Uehlinger U, Malard F. 2001. Understanding natural patterns and processes in river corridors as the basis for effective river restoration. Regulated Rivers Research and Management 17: 311-324.
Wiederkehr E, Dufour S, Piégay H. (2010). Localisation et caractérisation des géomorphosites fluviaux à l’échelle des réseaux hydrographiques, exemples d’applications géomatiques dans le bassin de la Drôme. Géomorphologie : relief, processus, environnement 2 : 175-188.
Wilbanks TJ. 2006. How scale matters: some concepts and findings. In: Reid WV, Berkes F, Wilbanks TJ, Capistrano D. Bridging Scales and Knowledge Systems, Concepts and Applications in Ecosystem Assessment, 21-35.